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ABSTRACT

A model for the analysis of simple human conceptual behavior, based on the apparent similarities of human conceptual behavior and that of infrahuman subjects, is developed. A minimum definition of conceptual behavior is given: A single response, verbal or nonverbal, under the discriminative control of a group of stimuli whose parameters are defined by the differential reinforcement of the environment. In addition to the role of differential reinforcement in the development of stimulus control, other variables which are very important for the form of that control are procedures effecting stimulus presentation or stimulus programming. It is likely that programming procedures play increasingly important roles in the development of conceptual behavior as that behavior becomes more complex. One important set of behaviors which appears to fall into successive levels of complexity is mathematics; an analysis of the behavior of counting is given. The model developed consists basically of two assumptions about concept formation: (1) concepts are discriminated operants, with the major controlling variable being differential reinforcement; and (2) learning set procedures teach an organism to discriminate and quickly respond to differential consequences, and the same lesson may be learned at a slower rate while acquiring a large group of concepts in childhood. (DB)


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BEHAVIOR ANALYSIS PROGRAM

BACKGROUND PAPER

# TOWARDS AN OPERANT ANALYSIS OF THE ACQUISITION OF CONCEPTUAL BEHAVIOR

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The papers in this series report work of interest to those connected with the implementation of Behavior Analysis Classroom programs. The series consists of research reports, background papers, and addresses presented to professional audiences by staff members of the University of Kansas Support and Development Center for FOLLOW THROUGH. The preparation of all reports in the series has been supported in part by a grant from the U.S. Office of Education [OEG-0-522422-4433(100)]. Points of view or opinions stated do not necessarily represent official government position or policy.

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# TOWARDS AN OPERANT ANALYSIS OF THE ACQUISITION OF CONCEPTUAL BEHAVIOR[1]

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There is probably no single term in the psychological literature which has a wider range of definitions or which is discriminative for a wider range of behavior than the term concept. In fact the term appears to have almost unlimited utility; it is possible to speak of learning a concept, or the "concepts" of children's learning. Concepts may be very simple such as "all squares" or they may be very complex such as the "concepts" of physics. Hull (1920) and Martin (1967) see concept learning as involving an extension of the principles of learning theory, while Bourne (1967) and Hunt (1962) see concept learning as such a distinctive process that it forms the boundary which distinguishes man from the other beasts. Kendler (1964) in a review of the area of concepts and concept formation notes that,

> This observation about the linguistic import of the term concept emphasizes the point that the present subject, as distinguished from the others in this symposium with the exception of problem solving, is not a technical term having its origin in a clearcut

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1. I wish to thank James A. Sherman, Donald M. Baer, and Don Bushell, Jr., for their suggestions and criticism which were essential to the writing of this manuscript.

> experimental methodology. Of course many respectable scientific concepts do have their roots in common parlance. They, however, achieve respectability and importance only after these original roots have withered and their place and function have been taken over by a technical term, or terms, that have the advantages not only of being less ambiguous but also, in the experimental sense, more meaningful. Although there are signs that this healthy course of development is beginning for the concept of the concept, the fact is that it is still vague and amorphous. This point is made to impress the reader that because of the scientific infancy of his topic, the writer is in that unenviable but not uncommon position of a psychologist who is not quite sure about what he is writing. This predicament nevertheless does have one advantage. It frees one from being constrained by any orderly array of facts and theories that demand a particular kind of systematic treatment. It allows for flights of fancy and broad generalizations without much fear of being embarrassed by any clearcut contradictory evidence. (p. 211)

While Kendler's own review is quite restrained, even conservative, he has put his finger on one of the basic difficulties of attempting to deal with the area of concepts and concept formation. There is no commonly agreed upon scientific definition of a concept. As a consequence the area of concept formation appears to be in a state of verbal disarray. This is most unfortunate since many important behaviors seem to be under complex stimulus control. Such behaviors as grouping and classifying objects on the basis of a common characteristic, forming relationships between objects or groups of objects, and verbal behavior in general are often pointed to as conceptual in nature (Deese and Hulse, 1967). Another multifaceted example of these sorts of behaviors can be found in mathematics, where the behaviors range from simple labelling, to counting, to more complex counting, addition,

subtraction, multiplication, and division are all variations of the counting operation (Campbell, 1919).

A wide range of important behaviors of varying complexity have been identified as being conceptual in nature. Further, if Kendler's brief evaluation of the area is accepted, these behaviors are also in need of extensive analysis and study. The next question might be what sort of assumptions are made about concepts and concept formation, and how these assumptions affect the approach to an experimental analysis of concepts. If an investigator were struck by the apparent complexity of what has been labelled conceptual behavior, then concept formation might be viewed as a uniquely human behavior. This assumption would lead him to study the acquisition of even simple single dimensional conjunctive concepts as a process completely distinctive from those studied in the experimental laboratory with infrahumans. It appears that Hunt and his associates have made some similar assumptions; as a consequence, they have taken a computer simulation approach to concept formation, in which the objective is to develop a model of how a rational logical adult might solve any conceptual problem.

> In a series of experimental studies, Hunt, Martin and Stone (1966) considered the question of how a rational problem solver ought to learn concepts, given some intuitively reasonable constraints on the cost factors in problem solving. To set the framework for the current experiments, a brief review of their reasoning is in order.
>
> The activity engaged in during concept learning can be divided into two phases, the action when the learner accepts and classifies items into the organizing set, and the action when the learner examines the current contents of memory in order to develop a

> new concept. We proposed that a rational learner would only enter the second phase, which presumably entails much more work, following an error of classification, since only then would he receive a signal that the hypothesis he was entertaining was, in fact, incorrect.
>
> We also suggested that concept learning be thought of as a game against an indifferent opponent, Nature. In this game Nature has one move, the choice of a particular decision tree as the correct answer. The learner has two moves since he chooses both a procedure for storing information in memory and a method for examining the contents of memory. Once these choices are made the game begins. (Hunt, 1967, p. 80-81)

However, if on the other hand the investigator is impressed by the apparent similarities of such human conceptual behaviors as grouping and classifying to studies of stimulus control of infrahuman behavior, it is likely he would make some strikingly different assumptions about the nature of concept formation. He might see it as an extension of such phenomena as generalization and discrimination. Sidman (1960) has made some persuasive arguments for proceeding from similarities rather than from differences:

> Are experimental findings obtained with one species generalizable to other species of organism? This is the problem of interspecies generality, and it has an unfortunate historical background. The solution propounded by many psychologists represents one of the last vestiges of the fallacy of man as the center of the universe. The fact of evolutionary change is accepted in other areas of biology; nevertheless, Behaving Human is often held to represent a discontinuous leap from Behaving Subhuman. Even many of those who do consider human behavior to have developed through a normal evolutionary process still think of man as something special. Furthermore, not only is man's behavior held to be different in principle from that of other organisms, but the behavior of any species is sometimes alleged to be different from the next lower one. With each evolutionary step, some advance must presumably have been made toward that ultimate achievement of which the psychologist is supposedly an example.

> This prejudice has produced a curious solution to the problem of species generality of behavioral data. Comparative psychology has become a discipline devoted largely to discovering differences in the behavior of various species of organism. When similarities, the stuff of which most sciences are made are found, they are dismissed as unimportant phenomena. Differences that point towards the development of higher-order processes as man is approached along the phylogenetic scale are selected as the only worthwhile comparative data.
>
> A comparative psychology that seeks to determine differences rather than similarities among species really has an easy time of it. Differences are not difficult to find. (p. 54-55)

An attempt will be made in the present paper to proceed on the basis of the apparent similarities of human conceptual behavior and that of infrahuman subjects, with the objective of developing a model for the analysis of simple human conceptual behavior.

A key word to the analysis of conceptual behavior is behavior, rather than conceptual. Keller and Schoenfeld (1950) make this point in their brief excursion into the area,

> "What is a concept?" This is another term which has come into psychology from popular speech, carrying with it many different connotations. We shall have to be careful in using it, remembering that it is only a name for a kind of behavior. Strictly speaking, one does not have a concept, just as one does not have extinction, rather, one demonstrates conceptual behavior by acting in a certain way. Our analysis should really start with a different question: What type of behavior is it that we call "conceptual"? (p. 154)

Unfortunately most theorists, including the behaviorally oriented mediational theorists, have shown a strong tendency to treat concepts as real things which exist in the mind. This is especially true of Piaget (a stage theorist) since his whole theory is based on the processes of

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assimilation and "accommodation" to the cognitive structure of the concept (Flavell, 1963).

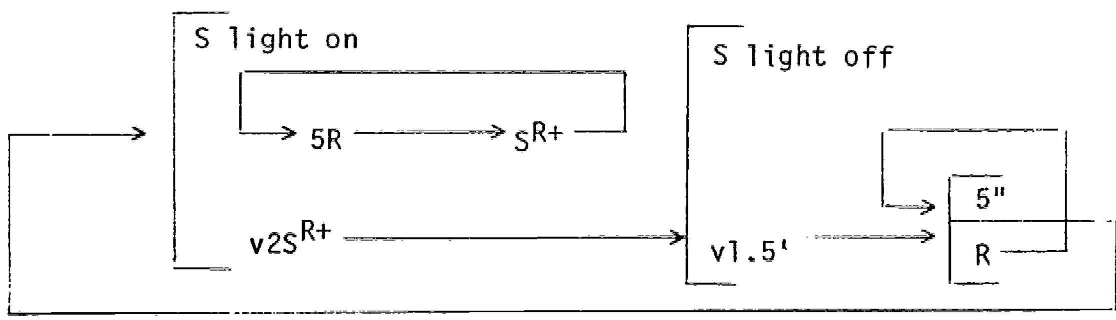
Keller and Schoenfeld concluded that the essence of concept formation is generalization within classes and discrimination between classes. Thus they argue that concept formation is a process based on two more widely studied and understood processes, discrimination and generalization. Millenson, in his 1967 text, takes a very similar position regarding the role of discrimination and generalization, basing his analysis on the development of $S^D$ and $S^\Delta$ control over the "conceptual," "classifying" or labelling" behavior.

Discrimination and generalization will be used in this paper strictly as descriptive terms or labels for sets of empirical functions whose properties seem to be derived from other procedures (mainly variations on differential reinforcement). While discrimination and generalization are often informally described as the two sides of a coin, this is a nice phrase which does not appear to be completely accurate. The coin analogy and others often imply that discrimination and generalization are two distinct discontinuous phenomena; while in practice, whether discrimination or generalization is emphasized is as much a function of the investigator as the data. Take for example a simple generalization gradient. As the response rate falls off as a function of the difference between the test stimulus and the training stimulus, usually there is no point where discrimination is said to occur. Yet in discrimination studies, the differences involved would frequently be sufficient for the investigator to conclude that discrimination had

occurred. The difference seems to be that in one case the investigator is studying generalization, while in the other he is studying discrimination. Terrace (1966) has gone so far as to suggest that both terms be replaced by the single term "stimulus control." However for the purposes of this paper, there appears to be some utility in being able to readily distinguish one end of the continuum from the other by the use of a simple label. While Terrace's (1966) work with errorless discrimination has raised some questions concerning the theoretical explanations of discrimination and generalization, knowledge of these two phenomena is at least sufficiently developed to the point where the behaviors in question may be easily produced. Sidman (1960) argues that this ability to produce and control is powerful evidence for the theory involved. So while the exact parameters of discrimination and generalization have yet to be worked out, they appear to offer a firm foundation for the development of an explanation of concept formation.

Michael (1963) in his introductory lab manual presents a simple method for bringing the bar pressing behavior of a white rat under the control of a light on - light off discrimination. The light is turned on in the chamber and every fifth response is reinforced with food. After an average of two reinforcers has been delivered, the light is turned off and bar pressing is no longer reinforced. After approximately one and one-half minutes, the light is turned back on if the animal has not responded in the last five seconds. If he does respond, the light is left off for another five seconds, until five seconds have passed without the rat responding. The whole sequence is repeated a number of

times until the rat exhibits the behavior of pressing the bar only when the li_'t is on.




This procedure very quickly produces the desired behavior; that is, the animal responds differently during the light on condition (presses the bar) than it does during the light off condition (does not press the bar). This difference in responding is attributed to the differential consequences attached to the lever press during the two conditions. The names typically given to the light on and light off conditions are $S^{D}$ and $S^{\Delta}$, an $S^{D}$ being a stimulus which marks the occasion when a response (in this case, lever pressing) will be reinforced, and an $S^{\Delta}$ being a stimulus which marks the occasion when a response will be followed by extinction (Bijou and Baer, 1961). However, what is most important about simple discrimination learning is that the organism comes to consistently make a response in the presence of one stimulus, and consistently makes that response less often in the absence of that stimulus.

The phenomenon of generalization, as it is typically studied in the experimental lab with infrahumans, consists of measuring the responses emitted in the presence of stimuli varying along some physical dimension after the animal has been reinforced for responding to a specific instance of that dimension. An example of this basic procedure is found in Terrace (1964a). Terrace reinforced responding to a positive stimulus (580 mu) without any explicit discriminative training; he then measured responding during extinction to stimuli of varying wave length. He found fairly high rates of responding to stimuli similar to the $S^+$ in wave length, 560 and 600 mu, with the rates falling off to almost zero as the difference in wave length became greater, 490 and 670 mu.

If an animal which has been exposed to the Michael procedure is given the opportunity to respond in the presence of a variety of monochromatic lights, it is likely that the rates of responding would be fairly high and close to equal. That is to say, there would be a flat generalization gradient along the dimension of light on. The animal was reinforced for responding when a stimulus light was on and not when the stimulus light was off. As a function of that training, it now responds to different colored stimulus lights. Whether the animal will continue to respond equally in the presence of these lights will be a function of what now happens following that responding. If the animal is now exposed to a procedure presented earlier as an example of a generalization study, (Terrace, 1964a), the typical generalization gradient may be observed. Next the animal is exposed to a procedure where responses in the presence of a stimulus (580 mu), usually labelled the $S^+$, will be followed by reinforcement on some intermittent schedule but responding

in the presence of a second stimulus (540 mu), usually labelled the $S^-$, will never be followed by reinforcement. After a period of exposure to this procedure, the animal will come to respond differentially in the presence of the two stimuli, responding at a high steady rate in the presence of 540 mu. This performance may be descriptively labelled discrimination, and the procedure a discrimination procedure. Yet the discrimination training has an effect on the observed generalization gradient. Whereas in the past there was a moderate rate of responding in the presence of the $S^-$ 540 mu and stimuli shorter in wave length (530, etc.), now there is zero or near-zero responding in their presence. Further, with procedures such as these, the highest rate of responding usually is observed not in the presence of the $S^+$ but in the presence of a stimulus on the side of the $S^+$ away from the $S^-$. This finding is usually called "peak shift" (Hanson, 1959, and Terrace, 1964a) and will be referred to in another context later in the paper. If the animal is given further discriminative training with a second $S^-$, this time slightly longer in wave length (600 mu), again it should be possible to observe changes in both the behaviors labelled discrimination and generalization. The generalization gradient should be very steep with little responding in the presence of the $S^-$'s or in the presence of stimuli on the bounding sides of the $S^-$'s, and high rates of responding in the presence of the $S^+$ and similar stimuli (570 and 590). Similar procedures may be used to refine this stimulus control even further to produce extremely steep generalization gradients. Theoretically, it appears possible to extend discrimination training to produce no

generalization gradient. That is, the subject will respond only to the specific training stimulus.

Further, this discussion has concerned itself with a description of these two empirical functions along a single physical dimension. It might be expected that in a complex situation they would occur along a number of dimensions. Reynolds (1968) has suggested an elementary rule for complex situations,

> Another rule applies to complex stimuli composed of separable parts. Generalization can be expected to occur to stimuli which have perceptible aspects in common with the stimulus that originally set the occasion for reinforcement. For example, if a pigeon's pecks on a triangle have been reinforced, the pigeon will be more likely to peck at stimuli with straight edges or sharp corners than to peck at circles or ovals, because stimuli with edges and sharp corners have those elements in common with the triangle. (p. 38)

Also it might be noted that the procedures discussed here all have involved differential reinforcement to increase discrimination and decrease generalization. However while it has not been extensively studied in the animal lab, the same differential reinforcement may be programmed to increase generalization. A study by Wolf, Risley and Mees (1964) may be used to exemplify this programming. However because of the nature of the procedures it can not be considered an experimental demonstration of programmed generalization. They had eliminated some of the deviant behaviors of a young boy and replaced them with more desirable behaviors. However this conditioning had taken place in an institution, using institution personnel rather than the child's parents. Wolf and his associates reasoned that if the child were sent home without further training, the home situation might be discriminative for

the old undesirable behaviors. So they exposed the child to what may be called generalization training. First the parents were brought into the institution, where they also differentially reinforced the appropriate behaviors. Next the child was sent home for brief periods of time, but an attendant who was an $S^D$ for the appropriate behaviors went home with him. Finally, the attendant took part less and less in the activity at home, with the parents providing the reinforcement for the appropriate behaviors. The procedures should have had the result of increasing the number of $S^D$'s controlling the responses, i.e. generalization.[2]

It is now appropriate to return to Keller and Schoenfeld's question about what behavior in the human is usually labelled conceptual. Taking a simple example, a young child might possess the response "dog" which he emits whenever he comes into the presence of any furry four-legged animal, whether it is "actually" a dog, cat, skunk, raccoon, etc. To insure that conceptual behavior is not being confounded with a limited verbal repertoire, the child is given two more mechanical responses, one to make when he sees a dog, and the other when the animal is not a dog, and he still responds in the same manner to all small animals. Then this child is not exhibiting behavior associated with the concept "dog" as typified by the verbal community, i.e. he does not discriminate between dogs and other small, four-legged animals. Now if this hypothetical child is watched over the next few weeks or months, it may be found that the environment is doing basically the same thing to the child's

2. For a more detailed discussion of discrimination and generalization, the reader is referred to Millenson (1967) and Terrace (1966).

response of "dog" that Michael's procedure did to the rat's lever pressing response (although the environment may be somewhat less systematic), bringing it under the discriminative control of the general class of stimuli dog. This control is achieved by reinforcement being provided for the response when it is emitted in the presence of a dog, but not when the stimulus is some other animal. Soon the child is observed emitting the response "dog" in the presence of the family dog and the neighbor's dog, but not as a label for the cat or pet skunk. At that point, it is still not clear that the child is exhibiting conceptual behavior; it could be that he has "merely" learned to discriminate between the family dog and cat, giving the response "dog" to one and the response "cat" to the other. The test of whether he really has learned the concept "dog" comes when Aunt Em brings her small grey poodle and large, grey, long-haired cat to visit. If he calls the poodle "dog" and does not call Aunt Em or the cat "dog" he has displayed a near-minimal criterion for conceptual behavior. That is, the response "dog" now has a generalization gradient which at this point includes new stimuli similar to the $S^+$ or $S^D$ (poodle), but not stimuli resembling the $S^\Delta$ or $S^-$ (cat).

Here then is a minimum definition of conceptual behavior: A single response, verbal or nonverbal, under the discriminative control of a group (often a broad set) of stimuli whose parameters (the extent to which generalization and discrimination will occur) are defined by the differential reinforcement of the environment. It may be noted that this definition of conceptual behavior may not satisfy a large

number of people [two notable examples might be Osgood (1953) and Hunt (1962)]. Osgood argues that if concepts were only basically discriminative behavior, then even rats would be able to learn them. Rather, he believes instead that concepts require some abstraction process. Osgood points to Fields' 1932 classic study, the "concept" of triangularity in the white rat (the " " are Osgood's), as an example of complex discriminative learning but he argues that it is not concept formation. Fields taught white rats to respond to triangles with a single consistent response, jumping from the Lashley jumping stand with the stimulus platform the only other elevated area within jumping distance. A puff of air was directed at the rat, usually forcing the jumping response. Because of the nature of the Lashley jumping stand, if the animal jumped to the door without the triangle, he found it locked and usually ended up falling into a net below the platform, apparently an aversive consequence for the rat. Under these conditions, the animals exhibited the correct choice behavior in the presence of new triangles of various size, color, position and shading of outline, i.e. conceptual behavior as defined above. Not so according to Osgood,

> Yet should we conclude that the rat can understand the abstract concept of triangularity? Would the rat respond positively to three dots in a triangular arrangement versus four dots in a square? Or react positively to three people, three places on a map, a three cornered block, as triangles? (1953, p. 667)

First, it is not clear what Osgood means by "three people, three places on a map." Are they arranged in the shape of a triangle? If not, if they were arranged in a straight line and the animal responded, would

it mean that all along the animal had been responding to the abstract concept of three? More to the point of Osgood's question, it appears that the best answer would be yes, if it was taught to do so, that is if differential consequences were provided for including three dots in the shape of a triangle in the class of discriminative stimuli controlling the jumping response. However, even if the rat did respond positively to the three dots in a triangle on the first trial, it is likely that the next question would be whether the rat would respond to three squares or rectangles arranged in a triangle.

The question raised by Osgood simply brings up the matter of analytical strategy. After an organism's behavior has been brought under some sort of stimulus control, either of two questions has a high probability of being asked. The first is associated with an analysis deriving from verbal logic, and is basically Osgood's question: What has the organism learned, i.e. did he learn the total abstract concept of triangularity in every way in which we ever discuss it? The alternate sort of question is tied closely to an empirical analysis of the data and might be, how far will this stimulus control extend? The second question is capable of being answered empirically; program various stimuli and observe if the animal does or does not respond. But the nature of the first question precludes its ever being answered except by some form of consensus. For example, it would be possible to argue that responding to three dots in a triangular arrangement is the essence of the abstract concept of triangularity, and if an animal learns that response it must be concluded that it now possesses the concept of triangularity.

It is possible that Osgood would disagree about this definition of triangularity. The ensuing discussion would then center on the essence of triangularity, but not on the data. The point is that while it is possible to argue with Osgood's logic, it would be next to impossible to disprove it empirically. On the other hand, it is possible by manipulation of the experimental procedures involved in the stimulus control to arrive at a statement of what appear to be the controlling variables involved in the behavior in question. In this case, a statement of what the animal has "learned" would consist simply of a description of these controlling variables.

While it is possible to speculate about what might have happened in the case of Fields' rats, there are a variety of more recent studies which indicate that the behavior of infrahumans does come under the discriminative control of very complex stimulus classes, i.e. concepts. One of the more striking demonstrations of this sort of behavior was carried out by Herrnstein and Loveland (1964). They trained pigeons to peck a key only when a translucent screen near the key was illuminated. Next, a variety of 35-mm. slides were projected on the screen. These slides consisted of natural settings of trees, meadows, towns, lakes, and so on. Half of the slides also contained people in various positions and settings. The pigeons were reinforced on an intermittent schedule for responding only when the slide on the screen at that time contained at least one person. The animals quickly came under the stimulus control of the presence of people. This control was maintained through several series of new slides (generalization). Also it appeared

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that the only time the pigeons had any trouble with this problem was when slides were presented which contained objects which are closely associated with people such as cars and houses with smoke rising from the chimney (versus houses without smoke - abstraction?). While the data from this study are certainly not unequivocal, Herrnstein and Loveland concluded that their pigeons' responding was under the stimulus control of what might be called a sophisticated concept of "person."

Hunt's objection to the notion that animals display conceptual behavior may be even less amenable to empirical evidence than Osgood's. Hunt (1962) maintains that before it is possible to conclude that the subject possesses the concept under study, he must be able to state the rule defining the concept. In general, Hunt's definition requires an explicit verbal statement of the relationship between the defining stimuli; the degree that the statement may vary from the "exact" defining relationship and still be correct is not clear. This verbal requirement of Hunt's appears to reflect two basic points about his position on concept formation; 1) Concept formation is a uniquely human phenomenon, therefore the requirement of a verbal statement eliminates the behavior of other organisms by fiat; 2) an overriding emphasis on the internal process of selecting or discovering the correct relationships between all of the possible stimuli rather than the overt behavior which may be presumed to be a function of these processes. As it was noted earlier, Hunt's position imposes

a disjunction between human conceptual behavior and the discrimination behavior of infrahumans. Is this a sound distinction?

In his classic investigation of concept formation, Hull (1920) found many subjects whose behavior came under the control of the distinctive discriminative stimuli of the concepts, but who could not state the rule governing their inclusion in the group. It is interesting to note that these failures were not confined to single subjects who failed to learn any of the rules, but were sprinkled throughout the behavior of subjects who could state most of the "rules." Thus it was not a failure of certain "types" of subjects to be able to state rules that were "controlling" their behavior, but a fairly widespread phenomena.

Long (1940) presents many strong arguments for the use of data other than verbal in the analysis of concept learning,

> But when subjects are used whose ability to verbalize is inadequate, an analysis of the relation of the behavior to the evoking stimuli permits certain important conclusions to be drawn in regard to the nature of the more subjective components of the response. Some forms of behavior remain unaltered notwithstanding radical changes in the environment. In these instances, it can be inferred that the stimuli are identical from the point of view of the response mechanism which they set into motion. Other variations in the stimulus conditions may call forth a different reaction and these conditions can be said to be non-identical or non-equivalent (4). The determination of the range of equivalence for a particular response will in turn yield information about the nature of the generalization which must be developing as a component of the response.
>
> If, in different experimental situations, where a wide range of stimuli are used, the subject is found to respond in a certain prescribed

> manner to only those factors which are common to all of the situations, then there must be a selective mechanism at work. (p. 290)

Long appears to be making the point that by systematically manipulating the stimulus conditions and observing the effects on the organism's responding, be it a rat, pigeon, chimp, or nonverbal child, it is possible to gain a great deal of information about the variables controlling the response, whether it is the conceptual behavior of a nonverbal child or the discriminatory behavior of a rat. Finally, Spiker (1960) reasons,

> Although some students appear to restrict concept formation to situations involving verbal responses of human subjects, others (e.g. Vinacke, 1951; Long, 1940) would include the nonverbal responses of preverbal children. In terms of available data, there is no good reason to exclude infrahuman subjects if perverbal human subjects are to be included. If these considerations are accepted, the formation of concepts in animals has already been demonstrated in transposition experiments. Thus, when chimpanzees are trained to select the smaller of two particular stimuli and subsequently choose the smaller of a new pair of stimuli, they have met the criterion of concept attainment. (p. 411)

The second point involved in Hunt's definition of concept formation is a function of the orientation that the concept is the classification rule while the actual response itself is trivial (Murdock, 1967). A first response to this point might be that the distinction itself is trivial. While it is unlikely that anyone would argue the point that the label "red" is a somewhat arbitrary label that in itself does not reveal the essence of the range of wave lengths called red, it is not therefore accurate to call it trivial. This notion that the response is unimportant reveals the bias Keller and

Schoenfeld cautioned against, that the concept is "real" and exists independently of the response and the environment. For while the response may be arbitrary, its occurrence or non-occurrence is a measure of the dimensions (stimulus control) of the concept (functionally similar $S^D$'s). The definition of a concept is based not only on the physical dimensions of the stimuli and the relationships between these stimuli, but equally important, it must include the relationships between these stimuli, the responses to them, and the consequences for making some of these responses in their presence. This essential characteristic of concepts often gets lost in the academic study of concept formation, since from the experimenter's point of view, he has defined the concept; the fact that the subject learns the definition of the concept through the differential consequences provided for making the response in the presence of some of these stimuli is for the most part ignored. Since this is a difficult point which is essential to the development of this analysis of concept formation, it is necessary to jump ahead to a group of concepts given the name disjunctive concepts. Disjunctive concepts differ from the conjunctive concepts in that there is no single stimulus property or set of properties which they all share in common. An example given by Goldiamond (1966) nicely illustrates this point; Goldiamond points out that the response of stopping is controlled by a group of stimuli which have no set of physical dimensions in common, such as an octagonal sign with the word "stop" on it, or a red light at an intersection, or the upraised arm of a man in a blue (typically blue) uniform. Goldiamond lists other stimuli which also control stopping

behavior. The important aspect of these stimuli which control stopping or which could be verbally labeled stop signs is that all only have one essential characteristic in common, the response of stopping or not stopping in their presence is likely to be differentially reinforced. Stopping in their presence is likely to avoid the presentation of some aversive stimulus while not stopping has a reasonably high probability of being followed by such aversive stimuli as a traffic ticket or an accident. It can be seen that in the case of disjunctive concepts, it is very difficult to speak about abstraction in the usual sense of a common property of all stimulus objects in the class. Rather generalization (responding to new instances) occurs around each member of the class, and whether that stimulus comes to control the stopping response depends upon the consequences which follow stopping or not stopping in its presence.

Cultural anthropology offers many other examples of variations on concepts which are taken to be real or true in Western society. Some of the more striking of these concepts deal with discrimination based on color and sound. A pair of field studies with the natives of New Guinea nicely domonstrate the function of differential reinforcement as the basis of a concept of color, even when the subjects could easily discriminate the members of the $S^D$ class from each other. Mead (1933) observed that these people had a color classification system so different that they saw yellow, olive, green, blue-green, gray and lavender as variations of one color. Mead concluded that since they were given the same name, they would be perceived as being the same. "There can be little doubt that when the same name is used for two

colors, they may be seen to resemble each other as a consequence." (p. 638) However Seligman (1901) had earlier found that when given the task of sorting wool samples, members of this same culture divide these samples on the basis of wave length rather than class name. So it is clear that they can and do discriminate between the physical properties of the colors which they give the same color label. The contrast between Oriental and Western music offers an example of two very extensive and distinct sets of concepts and relationships based on the same physical stimuli, the frequency of sound vibrations. The classical music of China and Japan divides this physical dimension into a sixteen tone system, while the traditional classical music of Europe and the United States is based on seven major tones.

Further indication of the dependence of concepts on the reinforcement variable is provided by Green (1955). Green had college students press a key when certain "correct" stimuli were presented in a display window, and not when other stimuli were presented. In this group design, the length of the stimulus presentation had values of three, thirty and sixty seconds while the schedules of reinforcement were CRF, FR15 and FR30. Green found that while the subjects' ability to discriminate (learn the concept) was a function of both the length of the stimulus presentation and the schedule of reinforcement, the schedule of reinforcement had the most powerful effect with the CRF producing the fastest learning and the FR30 the slowest irrespective of other variables. Interestingly enough, he also found that the subjects' ability to verbally identify the concept was inversely related to the intermittency of the schedule of reinforcement.

In a pair of semirelated studies, O'Connell and Wagner (1967) and Namikas (1967), again demonstrated the importance of differential consequences in concept formation. Ostensibly, the objective of the O'Connell and Wagner study was to investigate the effects of partial reinforcement on responding during extinction, while Namikas manipulated the relevance of pretraining and percentage of informative feedback. Both studies found that even a fifty percent schedule of partial reinforcement made acquisition more difficult than did a schedule in which each correct response was reinforced.

A more recent example of the effects of differential reinforcement on a discrimination problem, this time match-to-sample, is provided by a pair of studies, Sherman, Saunders and Brigham (1969), and a systematic replication now in progress by Sherman and Saunders. In the first study, preschool children were trained on complex match-to-sample problems (some involved line tilt, others geometric shapes). The apparatus consisted of a center display and button, and five other display - button pairs arranged in a circle around the center sample display. The children were given instructions to press the button under the display that looked like the one in the center. However, for a baseline period, all responses (match or mismatch) to lighted match displays were reinforced. The contingency was then changed so that only correct matches produced reinforcement. At the same time, one of the sample stimuli was removed from the series of stimuli being presented to the subjects. Most of the children's behavior quickly came under the control of the new reinforcement contingency,



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that is, they had a high rate of correct matching behavior. At this point, the sample stimulus which had been removed from the training series was reinstated as a probe stimulus. As a probe stimulus, there was no differential consequence for matching or mismatching when it was presented as a sample stimulus. The apparatus was simply programmed to present the next sample stimulus. The children displayed a high rate of correctly matching the probe stimulus. Next the probe stimulus was again taken out of the sample series and the general contingency was reversed. The children were no longer reinforced for matching but rather were reinforced for mismatching. That is, if the child pressed a button under a display which did not physically match the sample display he was reinforced. If he pressed the button under the stimulus which did match the sample stimulus, the next programmed sample stimulus was presented. Again the children's behavior came under the control of the reinforcement contingency and they displayed a high rate of mismatching the sample stimulus. Once more the probe stimulus was reinserted in the sample series, again with no differential consequences for matching or mismatching. This time the subjects responded to the probe stimulus by mismatching. So in this study, a stimulus which had no programmed differential consequences attached to responding in its presence came to control a specific response (matching or mismatching). There are a variety of possible explanations which are based on generalization or failure to discriminate. The children may have generalized across the physical dimensions of the stimuli and included these stimuli in the $S^D$ class. On the other hand, because the probe stimuli were procedurally

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imbedded in the reinforced stimuli, the children may have failed to discriminate that there was no differential consequence following responses to this stimulus. And finally, these findings may be related to those in the area of imitation and the development of generalized imitation (Baer, Peterson and Sherman, 1968). It may be that the children discriminated the consequences but respond according to the concept which has become a conditioned reinforcer.

There are a number of procedures which might factor out some of the variables involved in the production of this phenomenon. The probe stimulus might be presented in blocks of trials rather than imbedded singly in the other stimulus trials. Another method would be to briefly attach some differential consequences to responding in the presence of the probe stimulus; this is the method Sherman and Saunders are currently using in a follow-up study. After the initial phenomenon of the first study had been replicated, a brief five second time-out was made contingent upon correct responding to the probe (i.e. if the contingency in effect at the time was matching, correct matching to the probe produced the time-out). This procedure quickly, and so far permanently, eliminated the correct responding to the probe stimulus even though the time-out contingency was not again in effect for a large number of sessions. The procedure not only eliminated the correct responding to the probe, but also to a new probe stimulus that the subjects had never seen before in the experiment. While these findings do not solve the problem of what variables produced the phenomenon in the first place, they do indicate that a clear

differential consequence can quickly define the limits of the match-to-sample behavior in a limited stimulus sample.

These results, taken with those of Green (1955) and Goldiamond's (1966) discussion of disjunctive concepts again indicate the degree that any form of a discriminated operant, including concepts, is dependent on differential reinforcement for its definition and maintenance. That is, the number of stimuli included in the $S^D$ class and the extent to which generalization and discrimination occur is mainly a function of differential consequences programmed by the environment. For the natives of New Guinea, this resulted in a single concept of color whose controlling stimuli included $S^D$'s which varied widely in wave length. The match - mismatch behavior of the children in the Sherman et al. studies was under the control of the probe stimulus until differential consequences were briefly attached to responding in the presence of that stimulus.

Possibly most convincing are disjunctive concepts where generalization across the members of the $S^D$ class is not possible, and their control of a response as a class is clearly a function of the common contingency of reinforcement. So at the most elementary level, there appears to be fairly sound evidence for theoretically treating a concept as a discriminated operant, controlled by a complex class of $S^D$'s whose most important defining property is that of a common contingency of reinforcement.

If this proposition is seen as fairly reasonable, the next question which arises is why has the discrimination conditioning approach

to concept formation been largely ignored, discarded since the early fifties? Again, just as conceptual behavior in general did not appear to be amenable to an operant or behavioral approach, there are a group of phenomena in the area of concept formation as a whole which seem to preclude further analysis in terms of operant behavior, and demand at least a mediational explanation if not further cognitive speculation. Deese and Hulse (1968) comment:

> At the same time, it is a mistake to describe the learning of concepts as nothing more than a kind of passive process of discrimination, because we know that the behavior of human beings depends upon more than this. There is, for example, the matter of hypotheses in concept learning. Even more to the point, there is the matter of strategies. The use of strategies clearly lifts concept learning out of the domain of simple discrimination learning. (p. 422)

Unfortunately, most investigators treat these matters as if they lift the area out of the realm of any kind of discrimination learning, simple or complex. However this is not the only argument against discrimination learning; there seems to be a change in the form of concept formation with age. Many investigators in the area (see Vinacke, 1951; Spiker, 1960) have found that young children do in fact seem to learn their concepts by discrimination, such as the "dog" example, or Fields' rats' concept of triangularity. However it has also been well documented that this behavior seems to change not only in complexity (Piaget, 1953) but also in basic form (Kendler and D'Amato, 1955; Kendler and Kendler, 1959). In fact, the learning of children and adults frequently appears so dissimilar that various authors have felt it necessary to distinguish them by giving them different names.

Spiker (1960) makes the distinction between children's original learning which he calls concept learning and the behavior that adults display in the typical concept formation study, which he labels concept discovery since the subject already "knows" the concepts involved and merely has to put them together in the manner demanded by the experimenter. Vinacke (1951) makes a similar distinction, calling the one concept acquisition and the other concept achievement.

As Spiker points out, there is a paucity of studies of actual concept learning. However what few studies there are such as Gellerman (1933) I and II, Welch and Long (1940) A and B, and Long (1940) indicate that young children appear to learn simple concepts in a manner similar to the discrimination learning of infrahumans as studied in the laboratory. But in general, as the child grows older, this behavior changes. Piaget makes much of these changes with age in formulating his developmental stage theory of concepts, making age a major independent variable (Flavell, 1963). While the problem of whether concepts and concept learning pass through stages or not will not be argued here, studies by Deutsche (1937), Oaks (1947) and Ordan (1945) indicate that children differ in their concepts and use of concepts, largely on the basis of experience which is usually correlated with age but certainly not the same.

More clearly demonstrated in the work of the Kendlers is the fact that the discrimination learning of younger children and adults differs. Studies of discrimination, reversal and nonreversal shifts, show two distinct forms of behavior. Young children and infrahumans learn

nonreversal shifts much quicker than they learn reversal shifts, while the opposite is true for adults and older children. To make the phenomenon more explicit, suppose a subject is given a problem where the stimuli vary in color (red and green) and shape (square and circle). At first, the $S^D$'s are all red objects. But after the subject has learned that discrimination, the $S^D$ may be changed to all circles or all squares; this is called a nonreversal shift because responding to red is still sometimes reinforced. Alternatively, the $S^D$ might be changed to green, which is a reversal shift because red is now never reinforced. Because there is a constant difference in the ability of these two groups of subjects to learn these problems, the Kendlers have interpreted this finding as indicating that there is a change in learning behavior. Specifically, there is a change from simple discrimination learning to learning where the mediation of concepts plays the important role. That is, the mediational learner forms a concept or hypothesis about the correct one; therefore, each trial represents a confirmation or disconfirmation of that hypothesis which may be easily abandoned. As a consequence, the reversal shift represents a clear situation where the old hypothesis is no longer correct and the subject easily shifts to a new one. The nonreversal shift however represents a more ambiguous situation where it is difficult to completely abandon the old concept. The younger children and infrahumans face a somewhat different problem since they are learning by building up habit strength in some situations, and extinguishing it in others. In the nonreversal shift, some of the habit strength is still

appropriate; while in the reversal shift, it is necessary to extinguish all of the old responses. It is hypothesized by the Kendlers that this is a much slower process than confirmation or disconfirmation of a hypothesis.

Another set of data often pointed to as eliminating a discrimination analysis is that of one trial learning of simple conjunctive concepts (Crawford, Hunt and Peaks, 1967; Bower and Trabasso, 1964; Suppes and Einsberg, 1963). It is not that the subject takes one look at the stimulus card and says, "Aha, I got it." Rather, there appears to be a period of chance level performance, then perfect or near perfect identification of the concept. Again it is possible to analyze these data in terms of hypothesis testing, and an active search or a logical analytical approach to the problem by the subject. The logical analytical approach is the viewpoint favored by Hunt (1962). This position of course is not original with Hunt; English (1922) noted that some of his subjects began problems with the deliberate intention to analyze. This apparent intention to analyze appears again in the work of Bruner, Goodnow and Austin (1956). They conducted an extensive series of concept formation studies using fairly complex multidimensional concepts. By observing the responses made by their subjects to successive stimulus presentations, they inferred a variety of strategies that they believed the subjects were using to solve the problems. While a variety of "strategies" emerged, the most prevalent and usually most successful one was what Bruner, Goodnow and Austin called conservative focusing. In conservative focusing, the subject attacks a single

dimension at a time, say color. He might choose a single red circle with two borders; if that fails, he would then choose a single green circle with two borders. And so on, changing only one attribute at a time until the problem is solved.

So the acquisition of conceptual behavior or concept formation is surely not a simple process. In fact most interpretations of the phenomena make it a very complex process involving mediation, hypotheses, and logical analytic behavior (strategies). However just as the various definitions of conceptual behavior are interpretations and descriptions logically imposed on the data and not part of the data themselves, it may be possible to separate the interpretations of concept formation from the data of concept formation and develop a simpler explanation.

If as it has been argued differential reinforcement or consequence is possibly the most important variable in defining a concept, then it follows that a very important factor in the acquisition of successive concepts would be the ability to recognize and respond to the differential reinforcement produced by responses in the presence of the $S^D$'s and $S^\Delta$'s of any specific concept. Is there any process or procedure which might teach an organism just that? One widely studied set of procedures immediately comes to mind (a nice phrase at least), learning set. Learning set is a label given to a group of procedures invented, discovered, or produced (supply your own word as a function of your epistomological background) by Harlow (1949). Learning set procedures have been described extensively elsewhere (Harlow, 1959) so

only the bare essentials will be outlined here. Typically, an animal is given a series of successive two-object discriminations to learn. The apparatus is usually the Wisconsin General Test Apparatus and the stimulus objects are presented to the subject (typically a Rhesus monkey) on a tray. A reward is placed under the correct stimulus object which the subject receives for making the response of picking up that object. Thus differential reinforcement is provided for learning the correct cue or $S^D$. Each presentation of a stimulus is considered a single trial. The subject is presented the same stimulus pair, randomized for position, trial after trial until his performance reaches some specified criterion of correct responses in a row. He is then given a new problem consisting of two more stimulus objects which are functionally unrelated to the last pair (in learning set per se, all of the stimulus pairs are not related by some concept). The next pair is presented trial after trial until the animal learns this discrimination, and so on. As the procedure is carried out time after time with infrahuman primates and children, there is a distinct change in the organism's performance. On the first problems, the learning is slow and marked by many errors but as clocks of problems are looked at, the learning of each problem becomes more rapid until at some point depending upon the organism, the subject acquires the learning set. That is, when given a new problem, he chooses an object; if that is the correct object he will continue to choose that object. If it is not correct, he immediately shifts to the other object and correctly identifies it until a new problem is presented. In short, the

procedure has produced an organism which solves simple discriminations in a single trial. Someone unfamiliar with the procedure observing this terminal behavior might be struck by the similarity of the performance to that of humans learning simple concepts. It looks very much like the animal is using an elementary strategy; you test one hypothesis concerning which object is correct, if that is confirmed, you stick with it; if it is disconfirmed, you shift.

Of course the notion that learning set may be related to concept formation is not a novel one. Millenson (1967) and Harlow himself (1959) have noted that one way of teaching a concept would be to have all of the correct objects from problem to problem or across problems related by the concept in question, such as squareness. In fact this procedure is not only feasible but was used in 1940 by Long in his study of the concept of roundness in young children. In a study which seems to have been published and then forgotten, Long anticipated both Harlow's work and to a certain degree, programming, in using a procedure much like learning set. Successive two-object discriminations were employed, but all of Long's correct objects were related to the dimension of roundness. He also used a programmed sequence of stimuli to develop a generalized concept of roundness. He started with such three-dimensional objects as balls versus cubes, then cylinders versus rectangles, cones versus pyramids, and so on to two-dimensional objects. While Long's study is a nice demonstration of the use of procedures similar to learning set to produce a complex concept in children, the learning set procedure as first studied by Harlow is of

more interest for the development of a model for the acquisition of conceptual behavior. Harlow (1959) has analyzed his procedures in terms of what he has called error factor theory. In essence it is a single factor learning theory based on inhibition rather than excitation. Harlow argues that what the subjects are learning in the process is to inhibit a hierarchy of inherited response tendencies, such as position bias and the response shift tendency. This process goes on until the organism is able to inhibit all of these instinctual responses and respond only to the correct object. So Harlow's theory of discrimination learning is based almost solely on the development of inhibition. However as Holland (1967) points out in reviewing a paper by Martin (1967) which also presents an inhibition theory of discrimination, when generalization gradients of animals which learn discriminations with and without errors are compared, it is found that the second group does not exhibit the peak shift found in the performance of the animals who learned the discrimination by traditional extinction procedures. This peak shift is usually interpreted as a function of the generalization of inhibition developed to the $S^-$. Holland concludes:

> The fact that discrimination can be readily formed without developing an inhibitory stimulus disproves Martin's claim that discrimination occurs only "with a cost" and it would seem to have similar disastrous effects on the central role he gives inhibition in his theory of concept formation. (p. 75)

It might be argued that this evidence has the same effect on Harlow's inhibition theory. However it is not the objective of this paper to

to disprove any theory. Rather, it is to present an alternate, possibly simpler, explanation.

When closely examined, learning set procedures have a striking procedural similarity to another phenomenon already discussed in this paper, the disjunctive concept. It was argued that the definition of a disjunctive concept is based clearly on differential reinforcement. The same argument may be made for the definition of a correct response in learning set. A correct response is simply the response that is followed by reinforcement. This is the single consistent feature of all correct object responses; responses to them produce reinforcement. What may happen is that the animal's behavior after hundreds of trials comes under the immediate control of differential reinforcement, i.e. the animal responds to the differential reinforcement as defining the $S^D$ class. Skinner argued in 1938 that a response should be maximally conditioned as a function of a single reinforcement; this appears to be one of the theoretical points which he has abandoned over the years. However because of the nature of learning set procedures which make variables other than reinforcement irrelevant, it may in fact produce a situation where a clearly discriminable $S^D$ and the response can be maximally conditioned by a single reinforcement. Learning set procedures are of course the product of precise laboratory work but could they be used as a model for concept acquisition? Models at least in their initial form often consist of "what if" statements (Marx and Hillix, 1964). So, what if in the natural environment the problems and trials consist of more complex discriminations, i.e. concepts?

It would take longer, more experience and more trials, to develop the relationship between $S^D$'s and differential reinforcement, say the first five to six years of life. If that is the case, then it would not be surprising to find as the Kendlers (T. S. Kendler and H. H. Kendler, 1959) did that kindergarten children who rapidly learned an initial discrimination problem easily learned the discrimination reversal problem but had more trouble with a nonreversal shift; while the opposite was true of children who had difficulty with the first problem. The Kendlers analyzed their data in terms of mediation. However, if the first group could maximally use the defining relationship between $S^D$'s and differential reinforcement, their initial learning would be rapid with responses resulting in either the inclusion or exclusion of a particular stimulus from the class of $S^D$'s for that particular problem. Further, extinction would also be rapid in the case of the discrimination reversal where none of the old $S^D$'s are reinforced, leaving the subject free to quickly learn the new problem. On the other hand, this is not true for the nonreversal shift following the first problem. Responses to some of the old $S^D$'s still produce reinforcement and the definition of the $S^D$ class is much more ambiguous. According to this analysis, the converse should be true for the second group. Their initial learning should look more like the simple discrimination learning, perhaps like that of a primate, in the middle of learning set training. Extinction would not be rapid and the reversal shift would be more difficult than the nonreversal shift. Further, since learning set acquisition appears to be a continuous process, it would

be expected that the children would not be divided into two discrete groups but rather should fall along some sort of continuum. While the Kendlers do not present the individual data, they do state that the groups were divided on the basis of statistical analysis and probably were not two discrete groups. Of course this does not eliminate a mediational analysis, ". . .it seems reasonable to conclude that these, taken as a group were in the process of developing mediating responses relevant to this task and that some were further along than others" (Kendler and Kendler, 1959, p. 60). However, learning set acquisition has been demonstrated to be a continuous process while similar evidence does not exist for the acquisition of mediating responses.

If a subject is responding to the defining function of differential reinforcement, what might his performance look like when given a simple conjunctive concept to learn? It should look much like those observed by Bower and Trabasso (1964). That is, there should be a period of chance performance followed by perfect performance. Take the very simple problem of all red objects where the stimulus cards vary in color (red, green, and blue) and shape (square, circle, and triangle). Suppose the subject first chooses a green triangle. This stimulus complex of green triangle is followed by extinction, thereby reducing the probability that the subject will respond again in their presence. Next he chooses a red circle; the response to this stimulus complex of red circle is followed by reinforcement and immediately strengthened. At this point, since it is only a single

dimension problem the probability that the subject will respond to a red object may be assumed to be approximately 0.5 and the probability of a response to a circle also approximately 0.5. If the subject should choose a blue or green circle, it will be followed by extinction, leaving red as the $S^D$ controlling the choosing response. Consequently, he should choose red objects until a new problem is presented.

Of course this is a very elementary problem which can be made more complex by adding more dimensions to the stimulus objects and to the defining $S^D$ class. However Green's study (1955) indicated that there is another way of making a simple conjunctive concept difficult to learn which has nothing to do with the discriminative stimuli but rather with the relationship between the $S^D$'s and the reinforcement. When that relationship was clear and unambiguous (CRF), subjects had no difficulty in learning the problem, but as this relationship was made increasingly ambiguous (FR15 and FR30), the same problem became increasingly more difficult to learn.

Bruner, Goodnow and Austin (1956) increased the complexity of concepts under study by increasing the number of possible combinations of dimensions making up the defining $S^D$ class. Their stimulus objects varied in color (red, black or green), shape (square, circle or cross), and number of borders (one, two or three). As noted earlier, most of their subjects when faced with these complex problems exhibited a form of behavior which Bruner et al. labeled conservative focusing. The subject would make a choice and then vary one dimension of that

stimulus object at a time until the "relevant" stimulus dimension was discovered. How might a subject who has learned to respond immediately to reinforcement and extinction as defining operations perform in such a situation? It is reasonable that he would respond much like the behavior observed by Bruner, Goodnow and Austin. That is, because of his past history, he would respond in the way which is most effective in either conditioning or extinguishing a stimulus as a member of the defining class of $S^D$'s, i.e. by responding to one dimension of the stimulus object at a time.

Before the model is summarized, it should be noted that while the major emphasis of the paper has been on the role of differential reinforcement in the development of stimulus control, there are other variables which are very important for the form of that control. These variables may be summarized as procedures effecting stimulus presentation or stimulus programming. The most notable of these procedures at this time are associated with the work of Terrace (1963) and labelled errorless discrimination procedures. Traditionally, discrimination procedures have involved extinguishing responding in the presence of the $S^-$ or $S^\Delta$'s while reinforcing responding in the presence of the $S^+$ or $S^D$ (the Michael procedure presented earlier in the paper). Terrace's procedures involve what might be called the prevention of responding to the $S^-$. This is accomplished by developing responding to the $S^+$ and then introducing the $S^-$ at first for very brief time periods at a reduced intensity. Functionally at this point, the animal has little opportunity to respond in the presence of the

$S^-$; Terrace indeed suggests that the $S^-$ is best introduced when the animal is away from the response key. Next the intensity and duration of the $S^-$ presentation may be gradually increased (they may be increased singly or together) until they are equal to those of the $S^+$. The rate that these changes in the parameters of the $S^-$ are made is determined by the animal's performance; if the animal starts to respond in the presence of the $S^-$, the procedure is reversed and the animal is given more exposure to the $S^-$ at a level where it does not respond before proceeding. Terrace (1963b) has used similar procedures to transfer the stimulus control of a response from one set of $S^D$'s to another set. Goldiamond and Moore (1964) and Sidman and Stoddard (1967) have used these procedures to produce complex discriminations with normal and retarded children. At present, the full implications of these procedures for the development of stimulus control and conceptual behavior is not fully understood. The difference in the post discrimination generalization gradient has already been noted. On the negative side, Gollin (1968) suggests that errorless procedures may work to the detriment of a child who, after errorless training, has to learn a conditional discrimination made up of both the $S^+$ and the $S^-$. However a detailed examination of the pros and cons of errorless discrimination procedures is not the objective of this section; rather it is to point out some of the ways in which the programming of stimuli may affect the the development of stimulus control. While it is difficult to separate programming procedures from reinforcement procedures, it is likely that

programming procedures play increasingly important roles in the development of conceptual behavior as that behavior becomes more complex.

As it was noted in the introductory section, behaviors which vary widely in their complexity have all been labelled conceptual. The present paper has dealt entirely with what may be called elementary or simple conceptual behavior in an attempt to not only analyze these sorts of behaviors, but also to establish a base for the analysis of the more complex behaviors. One important set of behaviors which appears to fall into successive levels of complexity is mathematics. Learning labels for groups of objects, i.e. 1 for one object, 5 for five objects, etc., appears to be easily analyzable in terms of the procedures already discussed. However the behavior of counting (that is to say behavior other than that which may be attributed to rote memorization) appears to present some new problems. When a subject has learned to count, he may be presented with a new problem which appears to be new in a variety of ways in that both the stimulus may be new (not only consisting of a different sort of object but also in the number of objects) and the required response may be new in the sense that it has never been emitted in the presence of these stimuli. In a more concrete framework, suppose a child has been taught to count one through twenty-one objects by drill. Now he is presented with a stimulus which consists of twenty-five objects. This problem is different from all of the training problems in that it involves not only the

presentation of a stimulus that differs from the training stimuli but it also requires a response which differs from the training responses. If the child responds correctly at this point it might be concluded that the child knows how to count (a more cautious observer might say he knows how to count to twenty-five). The question is how did this happen, what procedures, variables, processes, etc. are involved in the development of this sort of behavior? It is likely that the reader will be hard pressed to answer that question. Here is an extremely important behavior about which a fantastically minuscule amount is known. Essentially counting is taught in this manner: The child is taught the numerals and their sequence one through ten, next he is taught that they are a label for a number of objects, finally the child is taught to count one to ten objects by drill. When he has learned these behaviors, the numerals are extended beyond ten and these procedures are repeated over and over until at some point the child learns to count. (The foregoing discussion was a simplification of procedures which I have noted while observing a variety of first grade and kindergarten teachers teaching math). At what point will the counting begin? Or stated another way, how much training is necessary for the development of counting? A related question is once the behavior has been developed in a limited sense, how far will it extend? That is, if the child now counts twenty-five objects, can he count thirty-five objects? Fifty-five objects? Or is further training on the response side of the problem necessary? These are all questions which have not been answered empirically and can only be speculated about.

One basic dimension of this behavior is emitting a new response in the presence of a new stimulus. This facet of the behavior may be related to other more widely studied behaviors such as match-to-sample and imitation which involve emitting new responses to new stimuli. Further, the procedures used to develop match-to-sample and imitative behavior may be important for the development of counting behavior. In match-to-sample procedures, a model or stimulus sample is presented to the organism, typically the subject then has to make some sort of response. As a consequence of that response, a number of other stimuli (at least two) are presented. One of these stimuli matches the sample of model stimulus along some dimension; in simple match-to-sample training it is usually an exact match, i.e. if the sample stimulus is a red triangle, the match stimulus will be a red triangle. There is a wide range of variations on this basic procedure (see Millenson, 1967, for a detailed discussion). One of these variations involves presenting the same problem until the subject learns it and then presenting a new problem. After this type of training, the subject will respond to a new stimulus by emitting the correct new response. This terminal behavior looks similar to the terminal behavior of learning set procedures in that the subject learns the new problem on the first trial. If learning set is analyzed in terms of differential reinforcement, then because of the similarity in procedures and results these match-to-sample procedures may be seen as an intermediate level of interaction between stimulus programming procedures with differential reinforcement procedures.

Ferster and Hammer (1966) attempted to teach binary arithmetic to chimpanzees using match-to-sample procedures. They were interested in studying language and language development without many of the experimental and analytical difficulties involved in working with human subjects. A number system was selected because number systems, like languages, have rules for generating relationships between their members much like grammar, and the binary system specifically because it consists of only two distinct numerals, 1 and 0. The terminal behavior that Ferster and Hammer were attempting to produce was the ability to perform all of the operations, addition, subtraction, etc. of binary numbers. Ferster's and Hammer's animals were killed in a fire before they had progressed this far. They were able to teach the animals a complex series of match-to-sample responses based on the numerosity of the sample. The animals were taught to respond to one, two, three and four objects by choosing the correct binary number 1, 10, 11 and 100, respectively. The behavior involved was as follows. A stimulus consisting of one, two, three or four objects would be presented in a center display. The chimp then pressed a key which was followed by the presentation of two binary numbers, one on either side of the sample display. Responses to the correct binary number were reinforced with food on some schedule. Responses to one, two and three objects were taught first, then stimuli containing four objects were introduced as a probe to see if there would be any transfer of the training to the new stimulus. There was not any appreciable effect, the animals

took almost as long to learn the new discrimination. Clearly the animals had not yet learned to count. However their behavior appears to be very similar to early behavior of children being taught to count. Would they have learned to "count" if these procedures had been continued? Other complex behaviors appear to yield to accumulative training; Baer, Peterson and Sherman (1967) were able to develop imitative behavior in non-imitative children by using similar procedures (they analyzed their procedures in terms of match-to-sample procedures). Lovaas, Berberich, Perloff and Schaeffer (1966) also used basically the same procedures to develop imitative speech in mute autistic children. However imitation training procedures and simple match-to-sample procedures as discussed earlier seem to differ from counting in one important dimension; in match-to-sample and imitation, the sample stimulus dictates the new response, (for example, in imitation the new response required is a response as close as possible to the model's response, i.e. the stimulus) this is not true of counting. It is true that in counting the new stimulus demands a specific new response; but the stimulus does not "model" the response as in imitative procedures. However, it may be that after the subject has been taught the behavior of generating new numerals, 10, 11, 12; 21, 22, 23; 31, 32, etc., then attaching these numerals to groups of objects, i.e. counting, may be developed as a function of procedures similar to match-to-sample procedures.

Further, in such an analysis the behavior of counting, while conceptual in nature, would not be considered a single concept.

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Rather it appears to be more useful in terms of analysis to consider it as being made up of a group of interrelated concepts. Supraordinate concept or interconceptual behavior are two labels which may be useful in indicating the relationship between what has been called a concept here and other more complex behaviors which are conceptual in nature.

While this review has not exhausted the vast variety of data which are often given the label concept formation, enough of the basic phenomena have been looked at to demonstrate that it is possible to develop a model which extends the experimental analysis of behavior to conceptual behavior and the acquisition of conceptual behavior. Basically the model consists of two assumptions about concept formation as defined in the present paper. The first assumption is that concepts may be described as discriminated operants whose controlling $S^D$ class can often become quite complex. However no matter how complex the $S^D$ class may become, the major controlling variable is the differential reinforcement provided for either responding or failing to respond in the presence of the specific $S^D$.

The second assumption is that learning set procedures teach an organism to discriminate and quickly respond to differential consequences, and that the same lesson may be learned although at a much slower rate over the course of acquiring a large group of concepts in childhood.

Finally, the model seems to offer more than mere theoretical continuity with the rest of operant theory. It has the advantage,

if accurate, of being able to suggest procedures which might be used to produce efficient concept acquisition, a basic problem for educational psychology. Consequently what is needed at this point is not further analysis of old data but the demonstration that the suggested procedures can in fact produce the behaviors in question.

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